RADIATION EFFECTS ON SILVER AND ZINC BATTERY ELECTRODES. IV.

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I. SUMMARY

The effects of gamma radiation on silver oxide battery electrodes at 90 and 60% states of charge were investigated in experiments designed to detect changes in discharge capacity, evolution of gases, and loss of solid material. A voltage follower circuit was incorporated into the automatic capacity measuring equipment to permit both recording and control of the test electrode potential against a reference electrode.

A capacity increase of 14% (± 4%) was observed in a series of cells that received a dose of 7 x 10⁷ rads (H₂O) of Co⁶⁰ radiation while cycling at 90 = 95% charge. The capacity of control cells in the same series increased 15% (± 2%). It is now evident that any capacity changes due to radiation under these conditions are small compared to the combined effects of cycling, temperature, and time. Following this conclusion, an effort was made to develop a preconditioning procedure for the compensation of these effects. Subsequent measurements at 60% charge indicated that this objective was approached, though not fully achieved, by preliminary cycling near full charge at an elevated temperature.

The loss of solid material from silver electrodes was significantly higher in the irradiated cells than in the controls. At the 90% charge level, a net loss of approximately 3% in silver content was associated with the irradiation process. The corresponding net loss at 60% charge was about 1.5%.

Mechanical loss from the cadmium counter electrodes was reduced by an order of magnitude through the use of smaller electrodes of similar construction, which required no trimming to fit the experimental cells.

The gas evolution data were improved by an exchange procedure that established a nitrogen atmosphere in the cells immediately before the irradiation stage. The gradual formation of hydrogen was again observed in irradiated cells, the final gas phase containing as much as 19% in two instances. After cycling, both irradiated and control cells contained significant amounts of oxygen.

Future work will include the study of silver electrodes at lower charge levels and higher radiation doses, the investigation of radiation effects on zinc electrodes, and the more specific characterization of gas evolution processes. Most of the radiation experiments will be performed at room temperature when a recently installed gamma facility becomes available for use.

II. INTRODUCTION

The prediction of battery performance on space missions requires an understanding of radiation effects on the cell components. Earlier work at Atomics International showed that damage from gamma radiation is incipient in the nickel-cadmium electrode system at the dose level of 10⁶ rads (H₂O). The present investigation is concerned with effects of gamma radiation on silver and zinc battery electrodes in 40% potassium hydroxide electrolyte. In the course of this program, two major chemical effects of radiation have been observed: (1) loss of material from the silver electrode and (2) evolution of hydrogen in experimental cells containing silver test electrodes and cadmium counter electrodes. 2, 3, 4 Preliminary data indicated that any radiation effects on the discharge capacity of the silver electrode were small at doses approaching 10^8 rads (H_2O). More stringent precautions were taken thereafter to improve the precision of the electrochemical measurements and to resolve effects of gamma radiation from those associated with temperature, ageing, and other variables. Studies of the silver electrode at 90% and 60% states of charge were continued in this report period.

III. EXPERIMENTAL

A. CELLS AND ELECTRODES

The experimental cells were assembled in stainless steel cases with three-compartment polystyrene liners, as described previously. 2,4

The silver test electrodes were sections of Yardney battery cathodes, cut to provide a capacity of approximately 0.4 amp-hrs. Two similar types of cadmium counter electrodes were used in this report period. The first was an electrode removed from the Union Carbide N-75 cell and trimmed to meet the experimental requirements; the second was a smaller cadmium electrode of the same construction, of the type used in the Eveready R-2 cell. Because the latter electrode required no trimming, it was more stable structurally.

The mercury-mercuric oxide reference electrode was described in the preceding report. ⁴ This electrode could be inserted in any of the cell compartments; it was usually placed in the central section, directly adjacent to the silver test electrode.

B. ELECTRICAL CIRCUITS

The existing circuits for automatic cycling and capacity measurement and for the recording of pressure were reviewed in the preceding report, and a modification involving a voltage follower scheme for use with a high impedance reference electrode was proposed. Since then, voltage followers consisting of operational amplifiers with direct feedback have been incorporated in both channels on one of the capacity measuring units. The modified circuit is shown in Figure 1. The standard cell in series with the measured potential introduces a recorder zero shift of 1.018 volts, so that the recorded

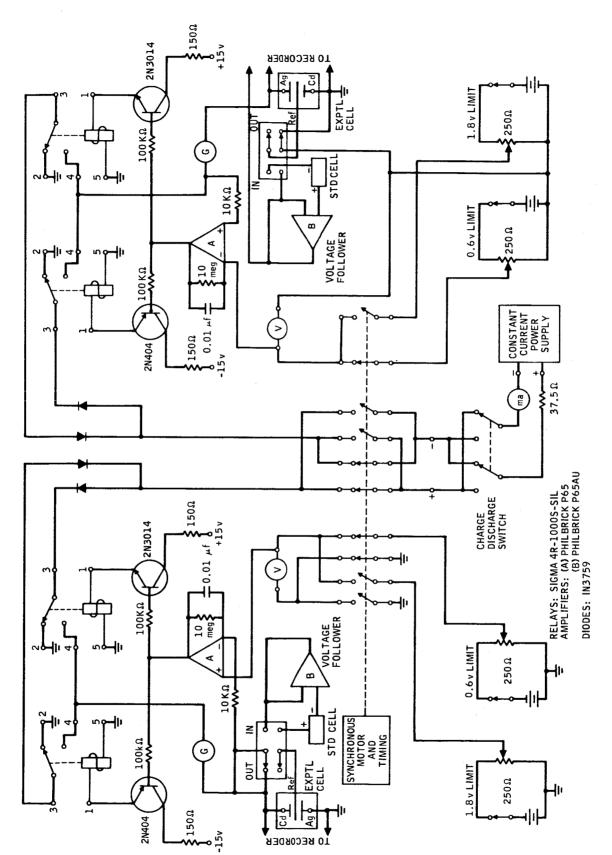


Figure 1. Modified Capacity Measuring Circuit

value for the silver electrode remains on-scale, and essentially the same voltage cut-off limits can be used. This arrangement permits both recording and control of the test electrode potential with respect to a reference electrode. By simple switching, the system can be returned to its original configuration, in which these functions are performed with respect to the working counter electrode. The new circuit minimizes the effects of ohmic drop and eliminates from the measurements any variations in counter electrode potential.

A minor change was also made in the timing mechanism of the automatic capacity measuring equipment. To speed the acquisition of data, the total length of the charge-discharge cycle was reduced by a change of gears from 18 hours to 15 hours. Four to five hours were required, typically, for charging or discharging a silver electrode at the standard current density of 7.2 ma cm⁻². Active phases of the cycle then totaled 8 to 10 hours. The shorter programming thus retained an adequate margin for variations among the individual electrodes.

C. GAMMA RADIATION SOURCES

The irradiation experiments were again performed in the ${\rm Co}^{60}$ source at the North American Aviation Science Center. The dose rate during this report period was 1.0 x ${\rm 10}^6$ rads (H₂O) per hour. The temperature in the radiation zone was ${\rm 40\text{-}45}^{\rm o}{\rm C}$.

The larger gamma radiation facility recently installed at Atomics International is expected to be available for use in the next quarter of this program. The new source will provide a variable dose rate up to 2.5×10^6 rads (H₂O) per hour and will contain ample space for multiple cells and auxiliary equipment. Without thermostatting, it will operate at ambient temperature.

D. PROCEDURES

The treatment of the cells in preparation and experimentation was essentially the same as that of the preceding report period. Each of the cells contained 50 ml of 40% KOH electrolyte. The gas exchange manifold and the helium leak detector were made available for use. A variation was made in the preliminary cycling procedure as a result of conclusions from Run CG-28.

1. Pre-Irradiation Cycling

In Runs CG-26 and CG-27, preliminary cycling was done at room temperature and $60 \rightleftharpoons 65\%$, the same state of charge as that used in the irradiation stage. However, beginning with Run CG-29, the cells were precycled at 45° and a capacity state of $90 \rightleftharpoons 95\%$, independent of the state during irradiation.

The latter procedure was adopted on the basis of a preconditioning study, Run CG-28, in which two similar cells were subjected to the following cycling sequence: (1) $90 \rightleftarrows 95\%$ for 24 hours, (2) $60 \rightleftarrows 65\%$ for 24 hours, (3) $60 \rightleftarrows 63.5\%$ for 60 hours. During the three successive stages of cycling, one cell was maintained at 45° , while the other was at room temperature. Discharge capacities were determined at room temperature after each of the cycling stages.

2. Leak Detection

In using the helium leak detector the assembled cells containing the electrolyte were put under a pressure of helium and then checked over the exterior for leaks before the final purging with nitrogen gas.

3. Nitrogen Purging

The gas exchange manifold was used to purge the cells with nitrogen.

They were first pressurized with nitrogen to slightly less than an atmosphere and then evacuated to approximately 0.5 atmosphere. This was repeated about ten times to ensure complete exchange of the gas phase. Finally the cells were sealed at atmospheric pressure.

4. Separation of Solids

Following the irradiation cycling and gas analysis, the solid material lost from the electrodes was collected and centrifuged with distilled water approximately twelve times. It was then dried for x-ray and emission spectrographic analysis.

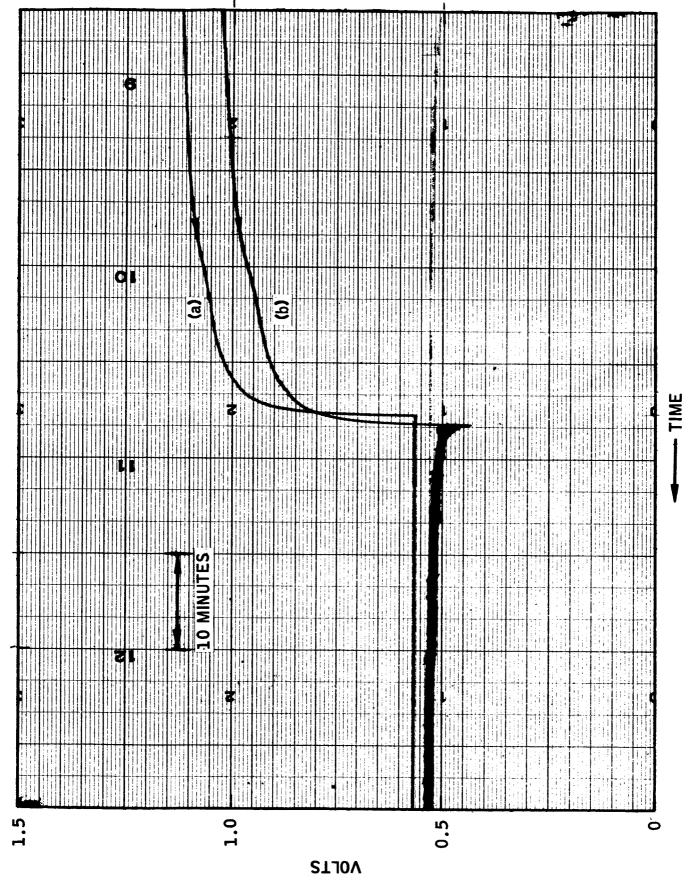
IV. RESULTS AND DISCUSSION

A. USE OF THE REFERENCE ELECTRODE

When the voltage follower circuits in Figure 1 are switched to the "IN" positions, the limit voltages for automatic control in the charge and discharge modes are referred to the potential difference between the test and reference electrodes. Any pair of electrodes in each cell may then be selected for recording. Figure 2 shows the silver-reference and silver-cadmium potentials, recorded simultaneously for the same cell while the discharge limit condition was approached and established. The discharge current was 7 ma cm⁻² at the silver electrode. The pen excursions resulting in the broad line for the silver-cadmium potential reflect primarily the presence of an ohmic drop across the fritted separator. Such excursions are absent in the silver-reference recording because the ohmic component was negligible in that case. A more detailed analysis of the control situations at the two limits is given in the following sections.

1. Control at the Discharge Limit

The silver electrode potential drops rapidly as the last portions of oxide are reduced. The electrode can be potentiostatted in this transition region, which is anodic to the hydrogen evolution range, with only a small demand for faradaic current. Since the electrode consists essentially of highly conducting porous silver, and the ohmic component in the solution has been largely eliminated from the control circuit, there is little or no demand of current for resistive power dissipation. Automatic control through the reference electrode is therefore highly satisfactory at the discharge limit. The frequency of the off-on current response decreases, typically, to the



Control of Silver Electrode Potential Against Reference Electrode at Discharge Limit Figure 2.

AI-66-83 8a

order of 0.1 cycle sec⁻¹ within a few minutes after the control system is actuated. The cell current then consists of short pulses with this repetition rate, and there is no serious interruption of current from the power supply in other branches of the circuit.

2. Control at the Charge Limit

The situation at the charge limit is more complex. The potential ranges for the formation of AgO and the evolution of oxygen are separated by only about 0.1 volt. The transition between these processes at constant current is therefore not a sharp one, and a substantial overcharge is usually required to make certain that the silver oxide electrode has reached its full capacity. This requires that the upper limit voltage be set within the oxygen evolution region, a condition which establishes a continuous demand for faradaic current. In addition, the oxide phase has a resistance that cannot be eliminated from the silver-reference electrode circuit. Because of these characteristics, the current must flow during a greater fraction of the time at the charge limit than at the discharge limit. The switching transients in the relay system then cause a noticeable decrease in the average output current from the power supply. In summary, the reference electrode is useful for controlling potential at the charge limit, but some of the problems associated with an off-on control system remain.

B. RADIATION EFFECTS

The experiments were designed to investigate the effects of gamma radiation in terms of capacity changes, gas evolution, and loss of solid material from the silver electrode. Results observed at 90 and 60% states of charge are discussed below.

1. Capacity of the Silver Electrode

Experimental conditions for the irradiation work performed during this report period are given in Table I. Detailed capacity data for the silver electrodes are recorded in Table II. The precision of \pm 3% within a series of repeated capacity measurements is typical of recent results at the 90% charge level. Table III summarizes capacity changes for the irradiated and control cells in several runs at this state of charge. An increase was observed in every case, following the high-temperature cycling stage (65 hours at 45°). The average change was 14% (\pm 4%) for the irradiated cells and 15% (\pm 2%) for the controls. It is now evident that these increases in the 90% runs were due to the combined effects of cycling, temperature, and time. Any superimposed capacity change due to radiation was negligible, within the precision of the measurements.

Four irradiation runs were made at 60% state of charge. The electrodes in Runs CG-26 and CG-27 were preconditioned by room-temperature cycling at 60\$\simes\$65% only. Both pre- and post-irradiation capacities in these runs showed downward trends on repeated measurement, and changes based on average capacities did not suggest a pattern of behavior. The preconditioning study reported in the next section was then conducted in an effort to develop a more satisfactory preconditioning procedure.

On the basis of conclusions from that study, the cells in Runs CG-29 and CG-30 were preconditioned by cycling at 45° and approximately $90 \rightleftharpoons 95\%$. In Run CG-29, the cycling current in the irradiated cell apparently went out of control during the irradiation stage. This accident produced excessive oxygen pressure in the cell. The observed capacity change of -3% (+2%) should therefore be considered with reservation. The capacity of the control

cell in the same run increased 4%, while that in Run CG-30 increased 8%.

These changes may be compared to an increase of approximately 5% predicted from the preconditioning study. The capacity of the irradiated cell in Run CG-30 increased an unexpected 15%. In prior work, capacity changes at 60% state of charge varied from -6% to +10% in irradiated cells and from -1% to -11% in control cells. Additional data will be required to characterize with certainty the behavior of capacity at this charge level.

2. Evolution of Gases

Final pressures and gas analyses for the irradiated and control cells are reported in Table IV. Although some final pressures below 1 atmosphere suggest the possibility of leaks at the source temperature, significant pressure increases occurred in most of the irradiated cells. Pressures in both control and irradiated cells were recorded during the irradiation stage of Run CG-26, by means of strain-gage pressure transducers, as described in the preceding report. Plots from these recordings are shown in Figure 3. The pressure-time function observed in this irradiated cell at 60% state of charge is similar in shape and magnitude to one recorded earlier at 90%. The pressure increase in Run CG-26 was due primarily to hydrogen evolution, according to the mass spectrographic analysis. A minor increase in pressure during the first few hours was caused by the temperature change.

The final gas phase in all cells contained argon, methane, and water as minor components. The methane appears to be derived from the polystyrene cell liner by a process not requiring radiation. The vapor pressure of water above the 40% potassium hydroxide solution is 26 mm at 45° and only 8 mm at 25°. A water content of the order of 1% would thus be expected for a saturated cell atmosphere at ambient temperature and pressure. The higher

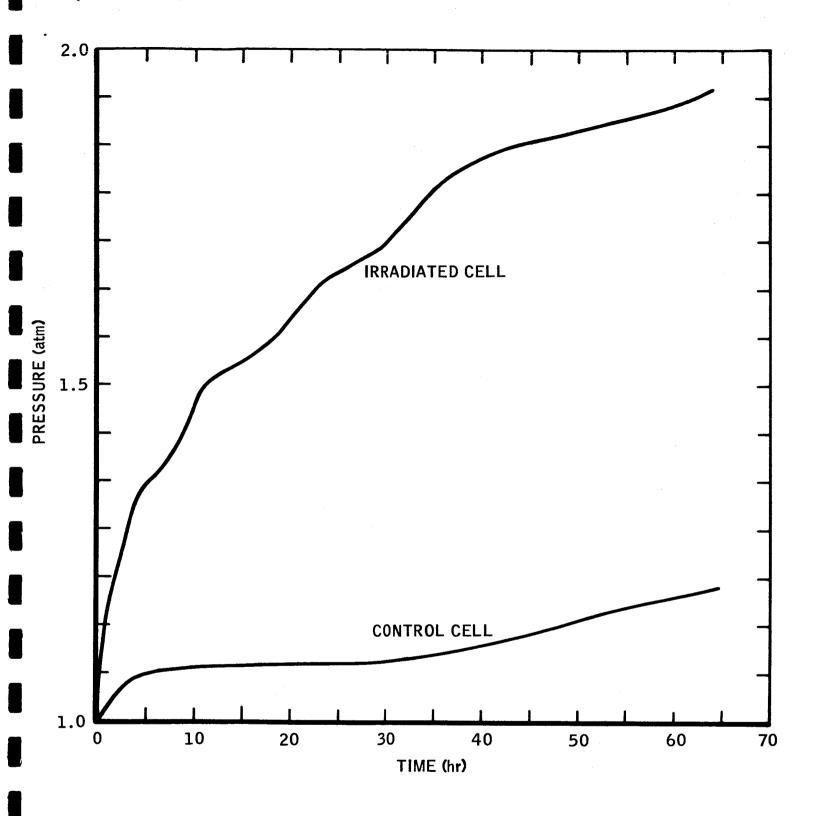


Figure 3. Pressure Change During Irradiation at 60% State of Charge

percentages of water found in the cells of Run CG-26 probably were caused by incomplete cooling before the gas was sampled.

Major gas components were nitrogen, hydrogen, and, in some cases, oxygen. The final nitrogen content in the control cells was 91 to 97%, following the introduction of the gas exchange technique. Oxygen in the cells may arise from several causes, including: (1) incomplete gas exchange before the irradiation stage, (2) undesired back-filling with air after leakage at the higher temperature, (3) asymmetry of the cycling current, (4) thermal decomposition of silver compounds, (5) radiochemical decomposition of silver compounds, and (6) radiochemical decomposition of the electrolyte solution. At the same time, oxygen can recombine with cadmium in the counter electrode. The abnormally high oxygen content of the irradiated cell in Run CG-29 apparently resulted from faulty control of the cycling current. In other cases, the oxygen content is difficult to interpret specifically because it may be affected by any or all of the variables mentioned above.

The source of hydrogen in the irradiated cells was discussed in an earlier report. 3 The radicals H and OH are produced by gamma radiation; extraction of oxygen from the hydroxyl radical, by cadmium, for example, would lead to a net evolution of hydrogen. The presence of 5 to 25% hydrogen in the irradiated cells is typical of previous results in this program. 3,4 The hydrogen contents of irradiated cells in Table IV fall within this range, and no trend appears with respect to state of charge of the silver electrode. Some experiments with only one type of electrode present would be of interest for the more specific characterization of hydrogen evolution reactions in relation to the silver electrode system.

3. Loss of Solids from Electrodes

Analytical data for solids recovered from the silver and cadmium

electrode compartments are given in Tables V and VI, respectively. The material from the silver compartment consisted principally of silver metal mixed with small amounts of silica from the cell separators and traces of cadmium hydroxide. The silver material losses were again much higher in the irradiated cells than in the control cells at both states of charge investigated. Losses in the cadmium compartments were greatly reduced by use of the untrimmed R-2 type electrodes. This improvement was also reflected in lower cadmium contents of the silver solids for the same cells.

C. PRECONDITIONING STUDY

Procedural details of the electrode preconditioning study, Run CG-28, are given in Table VII. The corresponding capacity data are recorded in Table VIII and presented graphically in Figure 4. Comparable plots for the control cells in Runs CG-26 and CG-27 are shown in Figure 5. In the 3-stage sequence, the 45° cell attained a stable capacity by the end of Stage 1 and showed only a 5% increase above this level, based on averages, by the end of Stage 3. In contrast, the average capacity of the room temperature cell increased 9% during Stage 2 and an additional 5% in Stage 3. The corresponding changes based on graphically evaluated capacities are smaller in each instance, but they follow the same trends.

From these results and previous observations, represented by Figure 5, it appears that high-temperature precycling near full charge is desirable to reduce the effects of temperature and/or time in prolonged irradiation runs. The use of control cells is still considered essential, however, since the capacity is not fully stabilized in a moderate preconditioning time such as 24 hours.

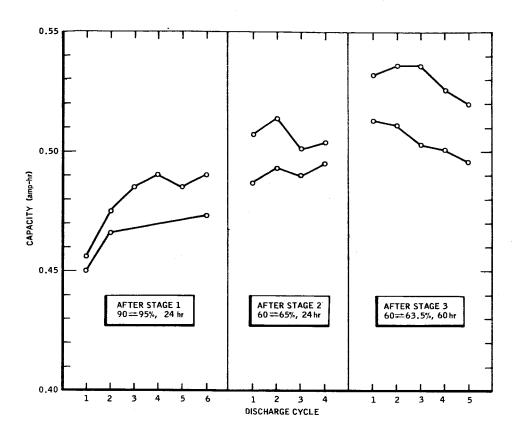


Figure 4. Preconditioning of Silver Electrodes at Different Temperatures

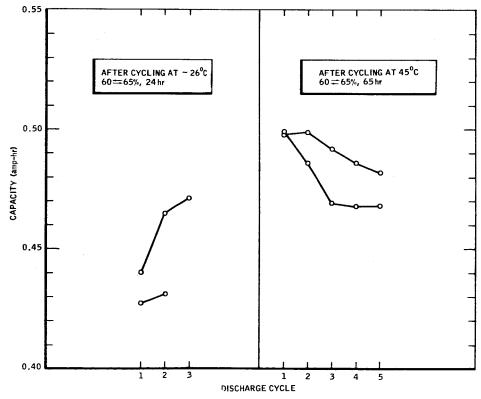


Figure 5. Conditioning of Silver Electrodes in Control Cells of Runs CG-26 and CG-27

V. PLANS FOR FUTURE WORK

Radiation effects on silver electrodes will be investigated further at 60% and lower states of charge. Cells will be exposed to higher radiation doses and higher dose rates when the new Co⁶⁰ source becomes available. Most of these exposures will be made at room temperature.

Parallel studies will be conducted on secondary zinc electrodes, following the establishment of required chemical and electrochemical procedures.

Gas evolution processes will be examined by present approaches and by supplementary experiments designed to eliminate the interactions arising from the presence of two different electrode systems.

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CONDITIONS FOR SILVER ELECTRODE RUNS TABLE 1.

	Initial State of	Silver Electrode	ectrode	Capacity Measurements Total Current	asurements	Pre-Irradiation Cycling	Irradiation Cycling
Run ^a	Charge %	Weight B	$\frac{\text{Area}^{\text{c}}}{\text{cm}^2}$	Current	Density ma cm ²	Temperature of	Current ^d ma
CG-24	06						
Irradiated Cell Control Cell		1.65 1.65	15.8 15.6	110	7.0	~ 26 ~ 26	92 83
CG-25	06						
Irradiated Cell Control Cell		1.40	13.6 14.2	100	7.4	~ 26 ~ 26	74 74
CG-26	09						
Irradiated Cell Control Cell		$\frac{1.55}{1.60}$	14.1 13.9	101.5 101.5	7.2	~ 26 ^e ~ 26 ^e	93.5 92
CG-27	09						
Irradiated Cell Control Cell		1.53 1.53	13.6 13.4	98 98	7.2	~ 26° ~ 26°	89.5 86
CG-29 ^f Irradiated Cell Control Cell	09	1.54 1.61	13.4 14.6	102 102	7.6	45 45	91 ^f 91
CG-30	09						
Irradiated Cell Control Cell		1.70 1.60	14.8 14.6	106 106	7.2	45 45	99 95

^a All irradiations were at 1.0 x 10⁶ rads (H₂O) hr⁻¹ dose rate, 6.5 x 10⁷ rads (H₂O) total dose

b Corrected for weight of leads, but including embedded silver grid

c Total projected area, including both sides

d Selected for 5% cycle depth in 15 minutes

e Runs CG-26 and CG-27 were precycled at approximately $60 \neq 65\%$; other runs in this table were precycled at approximately $90 \neq 95\%$

Excessive oxygen evolution occurred in irradiated cell, apparently due to inadequate current control

TABLE II. SILVER ELECTRODE CAPACITY IN IRRADIATION RUNS

	Initial									
	State of			Irradia	Irradiated Cell			Contro	Control Cell	i
Run	Charge %	Cycle	Pre-Test amp-hrs	Capacity △a	Post-Test amp-hrs	Capacity △ a	Pre-Test amp-hrs	$\frac{Capacity}{\triangle^{\mathbf{a}}}$	Post-Test amp-hrs	Capacity △ a
CG-24	06	1	p, c	1 1	0.490°	1	p, c	1	0.433 ^c	:
		2	0.415	+0.001	0.506	+0.005	0.455	-0.003	0.525	-0.003
		က	0.416	+0.002	0.501	000.0	0.459	+0.001	0.525	-0.003
		4	0.415	+0.001	0.497	-0.004	0.459	+0.001	0.525	-0.003
		ιΩ	0.412	-0.002	0.511	+0.010	0.432 ^b , c	1 1 t	0.544	+0.016
		9	1 1	!!	0.470	:	1 1	! !	0.486 ^{c, d}	1 1
		7	† 1	1 1 1	0.492	-0.009	1 1	:	0.523	-0.005
		Average	0.414	+0.002	0.501	+0.006	0.458	+0.002	0.528	+0.006
			Change +2	11% (+ 2%)			Change +15% (± 2%)	5% (± 2%)		
CG-25	06	1	0.357 ^b	1 1	0.422 ^b	1 3	0.369 ^b		0.422 ^b	3
		7	0.369	-0.005	0.419	+0.00+	€ I	t t	0.419	-0.011
		က	0.369	-0.002	0	1 1 1	0.365	-0.003	0.426	-0.004
		4	0.374	+0.003	0.415	+0.005	0.372	+0.004	0.426	-0.004
		ĸ	;	:	0.414	+0.00+	1 1	:	0.439	+0.00+
		9	1 1	:	0.390	-0.020	1 1	1 1 1	0.439	+0.004
		Average	0.371	+0.002	0.410	+0.010	0.368	+0.004	0.430	+0.007
			Change +1	.0% (+ 3%)			Change +17% (± 3%)	7% (+ 3%)		

TABLE II. SILVER ELECTRODE CAPACITY IN IRRADIATION RUNS (continued)

	Initial State of	.		Irradia	Irradiated Cell			Control	Ce11	
Run	Charge %	Cycle	Pre-Test amp-hrs	Capacity △ a	Post-Test amp-hrs	Capacity \^a	Pre-Test amp-hrs	Capacity	Post-Test	Capacity △a
CG-26	09	1	0.457	-0.010	0.498	+0.017	0.440	-0.019	0.498	+0.007
		7	0.481	+0.014	0.498	+0.017	0.465	+0.00+	0.499	+0.008
		ю	0.464	-0.003	0.484	+0.003	0.471	+0.012	0.492	+0.001
		4	;	; t	0.466	-0.015	;	;	0.486	-0.005
		ιC	:	i i i	0.457	-0.024	!	1 1	0.482	-0.009
		Average	0.467	+0.009	0.481	+0.012	0.459	+0.012	0.491	+0.006
			Change +3	3% (± 4%)			Change +7	+7% (± 4%)		
CG-27	09	1	0.434	-0.011	0.539	+0.025	0.427	-0.002	0.499	+0.021
		7	0.455	+0.010	0.522	+0.008	0.431	+0.002	0.486	+0.008
		ĸ	! !	:	0.507	-0.007	;	1	0.469	-0.009
		4	!	!	0.498	-0.016	1 9 1	1 1	0.468	-0.010
		ιC	!!!	! !	0.490	-0.024	:	:	0.468	-0.010
		Average	0.445	+0.011	0.514	+0.016	0.429	+0.002	0.478	+0.012
			Change +1	17% (± 6%)			Change +1	+11% (± 3%)		
CG-29 ^f	09	1	0.462	+0.007	0.435	-0.008	0.445	-0.011	0.464	-0.011
		2	0.457	+0.002	0.443	000.0	0.448	-0.008	0.473	-0.005
		e	0.455	000.0	0.456	+0.013	0.455	-0.001	0.489	+0.014
		4	0.450	-0.005	0.437	-0.006	0.456	0.000	0.478	+0.003
		ις ·	0.443	-0.012	0.443	000.0	0.475	+0.019	0.474	-0.001
		Average	0.455	+0.005	0.443 ^f	+0.005	0.456	+0.008	0.475	+0.006
			Change -3	3% (<u>+</u> 2%) [£]			Change +4	+4% (± 3%)		

TABLE II. SILVER ELECTRODE CAPACITY IN IRRADIATION RUNS (continued)

	Initial State of			1 1 1 1	ופין (פון פון פון פון פון פון פון פון פון פון			Control Cell	11a.	
	Charge		Pre-Test (Capacity	Post-Test Capacity	Capacity	Pre-Test Capacity	Capacity	Post-Test Capacity	Capacity
Run	%	Cycle	amp-hrs	_ Sa	amp-hrs	_a ∵a	amp-hrs		amp-hrs	⊳ a
CG-30	09	1	0.483	-0.011	.	0	0.470	-0.005	0.509	-0.004
		7	0.494	000.0	0.571	+0.002	0.477	+0.002	0.516	+0.003
		3	0.499	+0.005	0.592	+0.023	0.477	+0.002	0.535	+0.022
		4	0.502	+0.008	0.562	-0.007	0.477	+0.002	0.504	-0.009
		ĸ	1 1	1 1	0.557	-0.012	1 1	1 1 1	0.496	-0.017
		Average	0.494	+0.006	0.569	+0.011	0.475	+0.003	0.513	+0.011
			Change +1	5% (± 3%)			Change +8% (<u>+</u> 3%)	% (+ 3%)		

a Deviation from average

b Cell not at full capacity

c Omitted from average

d Erratic current

e Recorder pen out of order

 $^{\mathrm{f}}$ Excessive oxygen evolution occurred in irradiated cell, apparently due to inadequate current control

TABLE III. SUMMARY OF RECENT RESULTS ON SILVER ELECTRODES AT 90% STATE OF CHARGE

		Increase
Run	Irradiated Cell ^a	Control Cell
	%	%
CG-22 ^b	11 (+1)	
CG-23 ^b	15 (+3)	12 (+2)
CG-24	21 (+2)	15 (+2)
CG-25	10 (+3)	17 (-3)
Average	14 -4	15 +2

^a Total dose 7×10^7 rads (H₂O) Co^{60} gamma radiation.

b Ref. 4

TABLE IV. ANALYSES^a OF GASES AFTER IRRADIATION STAGE

	Initial State	Gas Volume	Total			/olume	Volume Percent	4.4	
Run	%	volume	mm Hg	00	N ₂	Ar	H ² O	CH ₄	H
CG-24									
Irradiated Cell	06	79.0	657	17.9		0.30	0.08	0.19	8.7
Control Cell		40.8	707	0.1	806	0.76	60.0	0.72	0.90
		•	•		,	,			
Irradiated Cell Control Cell	06	46.6 54.0	962 732	11.8 0.36	76.2	0.11	0.09	: :	11.8
CG-26									
Irradiated Cell	09	42.0	1087	2.4	72.4	0.05	4. 8	0.27	19.3
Control Cell		51.2	776	4.2	95.6	0.25	2.8	0.32	0.08
CG-27									
Irradiated Cell	09	47.7	884		82.0	0.02	1.14	0.14	12.13
Control Cell		56.8	969	5.1	93.4	0.16	0.92	0.13	1
CG-29									
Irradiated Cell	09	۹.	۹:	57.3 ^c	37.3	0.02	0.67	1	4.64
Control Cell		50.8	751	1.74		0.04	1.60	99.0	1
CG-30									
Irradiated Cell	09	47.8	066	•	78.9	0.04	1.01	0.12	19.3
Control Cell		44.9	816	1.01	9.96	0.07	1.16	0.39	1.07

a Mass spectroscopy

b Pressure exceeded range of manometer

^CExcessive oxygen evolution, apparently due to inadequate current control

TABLE V. ANALYSES OF SOLIDS RECOVERED FROM SILVER ELECTRODE COMPARTMENT

	Initial State					
	of Charge	Total Wt		Net Wt		
Run	%	mg	Wt % SiO ₂ a	mg	Identified	Wt Cd/Wt Ag ^c
CG-24	06					
Irradiated Cell Control Cell		58.0 9.0	99	ى بى بى	Ag Cd(OH)2	0.028
					7/110/10 19	0.15
CG-25	06					
Irradiated Cell		56.5	2	58	Ag	0.048
Control Cell		8.7	6	7.9	Ag	0
CG-26	09					
Irradiated Cell		25.2	9	23.7	Aσ	C
Control Cell		4.4	98	9.0	Ag	0 0
CG-27	09					
Irradiated Cell		20.7	4	19.9	Åφ	0 012
Control Cell		0.5	ក ! !	0 0 5	ָם מי	1 10 1 1
CG-29	09					
Irradiated Cell		12.4	0.3	12.1	Ag	0,020
Control Cell		6.2	0.3	6.1	Ag	0.010
CG-30	09					
Irradiated Cell		5.4	ָּט י	?	Ag	0.048
Control Cell		3.0	J ! !	~3	Ag, Cd(OH)2	0.091

a Emission spectroscopy

 $^{^{\}mathsf{C}}\mathbf{X} ext{-ray}$ fluorescence ^bX-ray diffraction

d Insufficient sample

TABLE VI. ANALYSES OF SOLIDS RECOVERED FROM CADMIUM ELECTRODE COMPARTMENTS^a

Run	Initial State of Charge	Cadmium Electrode Type	Total Wt	Wt % SiO ₂ b	Net Wt mg	Identified ^C	Wt Cd/Wt Ag ^d
CG-24 Irradiated Cell Control Cell	06	N - 75 N - 75 N - 75	118.0	1.7	116 71	Cd(OH) ₂ , Ag Cd(OH) ₂ , Ag	9.7
CG-25 Irradiated Cell Control Cell	06	N-75 ^e R-2	81.9 18.1	6.0	81 16	Cd(OH) ₂ , Ag Cd(OH) ₂ , Ag	20
CG-26 Irradiated Cell Control Cell	09	R-2 R-2	3.1	9 11	2.7 6.8	Cd(OH)2, Ag Cd(OH)2, Ag	0.40
CG-27 Irradiated Cell Control Cell	09	R-2 R-2	6.8 5.2	아마 아마 	7. ر 5. م	Cd(OH) ₂ Cd(OH) ₂ , Ag	0.12
CG-29 Irradiated Cell Control Cell	09	R-2 R-2	15.5 12.7	0.3 0.3	15.1 12.4	Cd(OH) ₂ , Ag Cd(OH) ₂ , Ag	2.2
CG-30 Irradiated Cell Control Cell	09	R-2 R-2	11.3	0.5	11.2	Cd(OH) ₂ , Ag Cd(OH) ₂ , Ag	1.9

a Combined solids from both cadmium compartments

b Emission spectroscopy
c X-ray diffraction
d X-ray fluorescence

Trimmed cadmium electrodes

Insufficient sample

TABLE VII. CONDITIONS FOR PRECONDITIONING STUDY

			Capacity Measurements	surements	ပ်	Cycling Conditions	
	Silver E	Silver Electrode	Temperature	Current		į	į
	8 80	'	O _O	ma cm	D _C	State of Charge	Time
Cell A	1.74	14.2	~26 ^d	7.3	~26		
Stage 1						90 € → 06	24
Stage 2						99 === 09	24
Stage 3						60 ===> 63.5	09
Cell B	1.80	14.6	~26	7.1	45		
Stage 1						66 ₹ 06	24
Stage 2						60 🚃 65	24
Stage 3					·	60 \longleftrightarrow 63.5	09
eg t		,					

Run CG-28; not irradiated

Corrected for weight of leads, but including embedded silver grid ρ,

c Total projected area, including both sides

d Room temperature

TABLE VIII. SILVER ELECTRODE CAPACITY IN PRECONDITIONING STUDY^a

	Cycling Temperature	Discharge	After Sta (90 : \$ 95%,	Stage 1 5%, 24 hrs)	After St. (60 7 765%,	Stage 2 5%, 24 hrs)	After (60 263.	Stage 3 5%, 60 hrs)
Cell	သူ့	Cycle	amp-hrs	٥	amp-hrs	◁	amp-hrs	Q
∢	26°	. -	0.450	-0.014	0.507	+0.001	വ	+0.001
		7	0.466	+0.002	0.514	+0.008	0.536	+0.005
		3	י י	1 6 8	0.501	-0.005	S	+0.005
		4,	۵ ۳ ا	1 1 1	0.504	-0.002	IJ	-0.005
		τ.	ا ا ا ا	t 1 1	1 1 1	1 1 1 1	S	-0.011
		9	0.473	+0.004	!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!	1 1 1 1 1 1 1	: ! !	1 1 1 1
		Average	0.464	+0.008	0.506	+00.00+	0.531	+0.005
			Change	nge e	+9% (+3%)		+5% (+2%)	
		Graphical	0.479		0.505		0.526	
			Change	nge e	+5%		+4%	
В	45	1	0.456	-0.024	0.487	-0.003	0.513	+0.007
		7	0.475	-0.005	0.493	+0.003	0.511	+0.005
		ĸ	0.485	+0.005	0.490	0.00	0.503	-0.003
		4	0.490	+0.010	0.495	+0.005	0.501	•
		ro.	0.485	+0.005	1 1 1 1	1 1 1 1 1	0.496	-0.010
		9	0.490	+0.010	:	t 1 1 1	1 1 1 1	1 1 1 1
		Average	0.480	+0.010	0.490	+0.003	905.0	+0.006
			Change	gee	+2% (+3%)		+3% (+2%)	
		Graphical	0.487		0.492		0.498	
			Change ^e	gee	+1%		+1%	

a Run CG-28; not irradiated
b Complete discharge in capacity measurement
c Room temperature
d Recorder pen out of order
e Percent of capacity after Stage 1

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